

VI. TECHNOLOGICAL FEASIBILITY OF THE PROPOSED REGULATION

In this chapter, we discuss the technological feasibility of the proposed regulation. In particular, we focus on the availability of the fuel that we expect most vessel operators will use to comply with the emission limits, and the ability of ocean-going vessels to use that fuel. In addition, we discuss possible alternative emission reduction strategies that vessel operators may use.

It should be noted at the outset that the proposed regulation does not require the use of any specific fuels. Rather, the proposed regulation requires vessel operators in regulated California waters to limit the emissions from their auxiliary engines to the levels of specified pollutants (diesel PM, NO_x, SO_x) equivalent to or lower than the levels that would have resulted had those engines used (1) marine gas oil (MGO), or (2) marine diesel oil (MDO) with a sulfur content of 0.5 percent or less. In 2010, the proposed regulation further reduces these limits to the level of emissions from an engine operating on MGO with 0.1 percent sulfur to maximize the regulation's emissions benefits.

Vessel operators can meet these limits in one of several ways. First, they can use MGO, or MDO with 0.5 percent sulfur or less, starting January 1, 2007. For the second tier (2010) limits, they can use MGO with 0.1 percent sulfur or less. As we stated above, vessel operators are not required to use these fuels, but there is an automatic presumption created that the operator has met the emission limits if he uses these fuels in the regulated engines.

Another way vessel operators can meet the emission limits is through the use of an approved Alternative Compliance Plan (ACP). The ACP provides a high degree of flexibility by allowing vessel operators to implement alternative emission control strategies, provided such measures achieve equivalent or greater reductions relative to the emission reductions that would have occurred by using the marine distillate fuels described above. Thus, if a vessel operator determines that there are overriding concerns justifying the use of other emission control strategies (e.g., safety during fuel switching, costs), the operator can seek, prior to entering California waters, ARB approval of an ACP, under which the operator would achieve equivalent or greater reductions using measures that the operator chooses. In this way, the vessel operator maintains full control in determining which emission reduction strategy is best suited for each particular vessel, with due consideration for safety, costs, and other factors important to the operator.

A. Availability of Marine Distillate Fuels

The term "marine distillate" refers to specific grades of marine distillate fuels. The proposed regulation allows the use of MGO that meets the specifications for DMX or DMA⁴ grades as defined in Table I of the International Standard ISO 8217 (as revised in 1996). The proposed regulation also allows the use of MDO (limited to 0.5 percent

⁴ "D" means distillate, "M" means marine, and "A" is the grade of the fuel.

sulfur), which is fuel that meets all the specifications for DMB grades as defined in Table I of the International Standard ISO 8217 (as revised in 1996). DMA is the most prominent marine distillate, and is available in the largest quantities. DMX, which is similar in specification to CARB diesel, is used in smaller amounts and is required for use in emergency back-up engines on vessels. DMB is basically DMA containing a limited amount of residual fuel (heavy fuel oil), typically due to storage or transfer of DMA in tanks or piping that previously held residual fuel.

In this section, we present information on the international fuel specifications for marine distillates, data on the current fuel sulfur levels found in fuels supplied to ocean-going vessels, and information on where vessels that come to California ports normally fuel. In addition, we discuss our findings with respect to the volume of fuels needed to comply with the proposed regulation and the impact the proposed regulation could have on the availability of marine distillate fuel worldwide. We also provide our preliminary findings on the availability of lower 0.1% sulfur distillate fuels we expect most vessels will use to comply with the proposed 2010 emissions limits.

Fuel Sulfur Specifications for Marine Distillates

The majority of marine distillates produced and sold worldwide conform to fuel quality standards categorized under ISO 8217. These standards place limits on the fuels' chemical and physical properties, including sulfur content. Table VI-1, Fuel Specifications, lists the sulfur content and flashpoint of land and marine based fuels that can be used to fuel compression-ignition ("diesel") engines. The sulfur content of a fuel is important because the lower the sulfur content of the fuel, the lower the PM and SO_x emissions. Flashpoint is important for safety reasons; the minimum flashpoint for marine fuels is 60 degrees Celsius. (ISO 8217, 1996).

In general, land-based fuels are required to meet more stringent State and federal sulfur specifications than marine distillates. As shown in Table VI-1, the lowest sulfur content specifications are for land-based distillates – with the exception of U.S. EPA off-road diesel. However, this exception will not be long-lived since the U.S. EPA off-road diesel specifications will in 2010 be harmonized with the on-road diesel specifications effective in 2007. The marine fuels also differ from land-based distillates in the minimum flashpoint specification. The lowest sulfur content specifications for fuels that meet the flashpoint specification for marine applications are found in the specifications for marine distillates. In contrast the highest sulfur content specifications are found in residual marine fuels (heavy fuel oil).

Table VI-1: Fuel Specifications

| Primary Use | Fuel Type | Fuel Grades | Fuel Specifications | Maximum Sulfur (%) | Maximum Sulfur (ppm) | Minimum Flashpoint (Centigrade) |
|--------------------|-------------------|---|----------------------------|---------------------------|-----------------------------|--|
| Land | Distillate | CARB Diesel (2006) Ultra Low Sulfur Diesel (ULSD) | No. 2-D | 0.0015 | 15 | 52 |
| Land | Distillate | CARB Diesel (current) | No. 2-D | 0.05 | 500 | 52 |
| Land | Distillate | U.S. EPA Diesel | No. 2-D | 0.05 | 500 | 52 |
| Land | Distillate | Off-Road U.S. EPA Diesel | No. 2-D | 0.5 | 5,000 | 52 |
| Marine | Distillate | Marine Gas Oil (MGO) | DMA | 1.5 | 1,500 | 60 |
| Marine | Distillate | Marine Diesel Oil (MDO) | DMB | 2.0 | 2,000 | 60 |
| Marine | Residual | Intermediate Fuel Oil (IFO) 180 | RME/F-25 | 5.0 ¹ | 50,000 | 60 |
| Marine | Residual | Intermediate Fuel Oil (IFO) 380 | RMG/H-35 | 5.0 ¹ | 50,000 | 60 |
| Marine | Residual | Bunker fuel | RML-55 | 5.0 ¹ | 50,000 | 60 |

1. The International Maritime Organization (IMO) MARPOL 73/78 Annex VI, Regulations for the Prevention of Air Pollution from Ships, entered into force in May 2005, lowers the sulfur cap on residual fuel from 5.0% to 4.5% in 2007.

Fuel Sulfur Properties of Currently Available Marine Distillates

The fuel specifications discussed above essentially establish limits that cannot be exceeded for sulfur content and flashpoint. As shown, marine distillates meet the most stringent sulfur specification for marine fuels. In order to assess the impact on emissions from the use of marine distillates, staff evaluated the actual fuel sulfur properties of marine distillate fuel currently available. The two sources of fuel property information staff reviewed were the ARB Oceangoing Ship Survey and the Det Norske Veritas Petroleum Services fuel sample data. (DNV, 2005). The results are summarized in Table VI-2 and discussed below.

Table VI-2: Current Sulfur Properties of Marine Fuel

| Fuel Specification | Average Fuel Sulfur Content (wt. %) | |
|--------------------|---|-----------------|
| | ARB Survey (CA Vessels) | DNV (Worldwide) |
| DMA | 0.5% | 0.38% |
| DMB | (survey asked for marine distillate sulfur content) | 0.65% |
| Residual | 2.5% | - |

The ARB Oceangoing Ship Survey (ARB Survey) was sent out in January 2005 to 158 vessel operators and agents. The survey requested information about ocean-going vessels that visited California ports in 2004. To date, we have received information on 327 vessels that visit California ports. This represents about 17 percent of the total number of vessels that visited California in 2004 (ARB Survey, 2004).

From the survey responses, staff estimates that the average sulfur content of marine distillate fuels used in auxiliary engines is about 0.5 percent. (Note: Separate sulfur content estimates for DMA and DMB were not requested in the survey). The average sulfur content of residual fuel was reported to be about 2.5 percent. Both are well below the maximum specifications listed in Table VI-1, which are 1.5 to 2.0 percent for marine distillates and 5.0 percent for residual fuel.

DNV performs a service to the marine industry by sampling and testing marine fuels from many suppliers in ports throughout the world and claims to be responsible for testing 70 percent of the marine fuel tested worldwide. DNV collected samples of marine distillates from ocean-going vessels in 2003. (DNV, 2003) The average sulfur content of samples of DMA taken worldwide was 0.38 percent sulfur by weight – well below the 1.5 percent standard. For DMB, the average sulfur content from the samples was 0.65 percent sulfur by weight – well below the 2.0 percent standard. Among the different areas of the world, averages are calculated from the samples taken at each port. The minimum and maximum average sulfur content samples of DMA taken from any one area of the world were 0.05 percent (Mexico) to 0.97 percent sulfur (Saudi Arabia). The minimum and maximum average sulfur content samples of DMB taken from any one location in the world were 0.05 percent (Mexico) to 1.30 percent sulfur (Germany).

Table VI-3 lists the average marine distillate sulfur contents for those areas of the world where ocean-going vessels that operate in the Pacific Rim have historically refueled. As shown in Table 3, the sulfur content of marine distillates varies widely. Figure VI-1

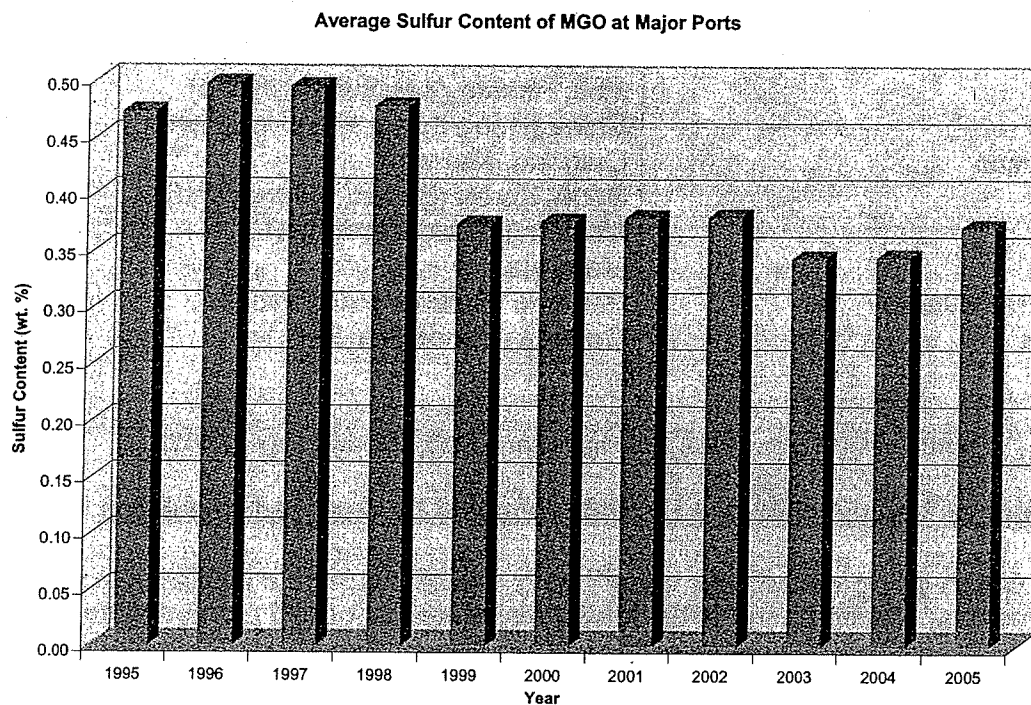
shows the historical average sulfur content of all samples taken in these areas of the world over the last ten years. As shown, the average sulfur content has ranged from a high of about 0.50 percent to a low of about 0.35 percent. Although historical trends are no guarantee of future sulfur levels, staff believes current and future regulatory efforts to lower sulfur levels in all types diesel fuels will result in the average sulfur levels continuing to decline over the coming years; specifically, regulatory efforts to reduce emissions from diesel engines in California, the United States, Japan, and Europe.

Table VI-3: Marine Distillate Average Sulfur Content (weight % Sulfur)

| Area of World | MGO | MDO |
|---------------|------------|------------|
| | DMA | DMB |
| Netherlands | 0.30 | 1.02 |
| Malaysia | 0.40 | 0.36 |
| Mexico | 0.05 | 0.05 |
| Panama | 0.42 | 0.42 |
| Canada | 0.21 | 0.24 |
| Singapore | 0.53 | 0.53 |
| Japan | 0.12 | 0.77 |
| Hong Kong | 0.39 | 0.42 |
| Korea | 0.81 | 0.87 |
| China | 0.29 | 0.32 |
| United States | 0.23 | 0.68 |
| Average | 0.34 | 0.52 |

(Source: DNVPS, 2003)

Figure VI-1: Sulfur Content of MGO at Pacific Rim Refueling Ports from 1995 to 2005



(Source: DNV, 2005)

Availability of Marine Distillate Fuel

Marine distillate fuel is currently available in most areas throughout the world. (Beicip-Franlab, 2003). Vessels typically obtain marine distillate via fuel barges, where the fuel is loaded on the barge either directly from a refinery terminal or from a storage tank at that is dedicated to marine distillate fuels. Based on discussions with vessel operators, a key factor in determining where to refuel is finding a fueling location within a vessel's current route, where it is available at the lowest cost.

Table VI- 4 provides a listing of ports where ocean-going vessels that operate in California waters have historically refueled either before or after operating in California waters.

Table VI-4: Common Refueling Ports for Vessels that Visit California

| Vessels that Visit California Ports May Refuel at the Following U.S. or International Ports | |
|--|-------------------------|
| U.S. Port Locations | International Locations |

| | |
|--------------------------|--------------------------------------|
| Los Angeles (POLB, POLA) | Netherlands (Rotterdam) |
| Santa Barbara (Hueneme) | Singapore |
| Puget Sound | Japan (Shimzu, Tokyo, Osaka, Nagoya, |
| Oakland | Moji, Hakata, Yokohama, Kobe) |
| San Diego | China (Hong Kong, Ningbo, Chiwan, |
| San Francisco | Quigdao, Xiamen) |
| Savannah | South Korea (Busan, Kwangyang) |
| Honolulu | Mexico (Lazaro Cardenas) |
| Norfolk | Malaysia |
| New York/New Jersey | Panama (Balboa, Manzanillo) |
| Charleston | Canada (Vancouver, B.C.) |

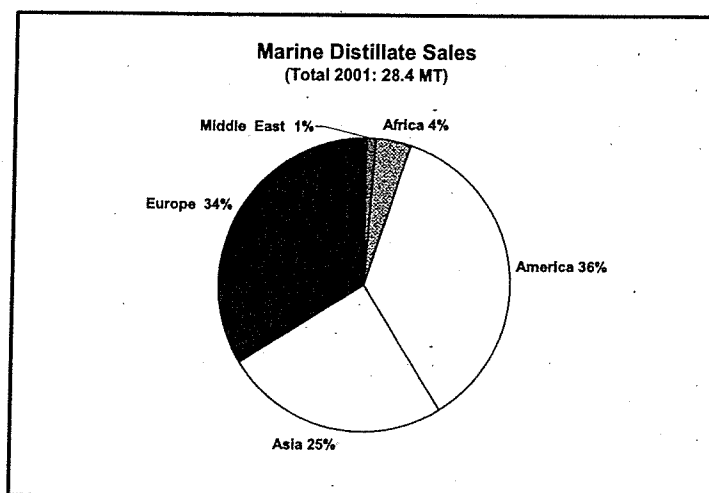
(ARB Bunker Survey, 2005; Correspondence, 2005; Starcrest Report, 2005)

Impact on Volume of Marine Distillate Required by Proposed Regulation

Currently, ocean-going vessels use either heavy fuel oils or marine distillates in their auxiliary engines. Based on the ARB Survey responses, about 75 percent of the oceangoing vessels use heavy fuel oil in their auxiliary engines and 25 percent use marine distillate. As stated earlier, we expect most vessel operators will use marine distillates while within 24 nm of the California coastline to comply with the proposed regulation's emission limits.

Assuming all vessels elected to comply with the proposed regulation by using marine distillate, staff estimates that approximately 46 million gallons (150,000 metric tons) of low-sulfur marine distillate would be needed in 2007 and 61 million gallons (200,000 metric tons) would be needed in 2010. This equates to less than 1 percent of the current total sales, 28.4 million metric tones (MT), for marine distillate worldwide. The distribution of marine distillate sales throughout the world is shown in figure VI-2. Marine distillate sales are highest in areas where Pacific Rim vessels have historically refueled -- Asia, Europe, and America. (Beicip-Franlab, 2003; Marine Distillate Volume Calculation, 2005).

Figure VI-2: Worldwide Marine Distillate Sales



Based on the reasons discussed above, staff believes that the relatively small additional demand for marine distillate likely to be created by this rule will be met by existing refineries without significant modifications to existing infrastructure. However, operators who choose to replace all residual fuel used in their auxiliary engines with marine distillate may experience some scheduling conflicts and logistics issues when loading large amounts from local suppliers (e.g. 1,400 MT or more). We cannot predict the extent to which these delays may occur, if at all, but the primary limiting factor in these situations is the capacity of barges dedicated to carrying marine distillate fuels. (Barge Capacity, 2005)

Some commenters have suggested during the informal phase of this rulemaking that the proposal's emission limits based on the use of MGO be based instead on MGO that is capped at 0.5 percent sulfur. We do not agree with this suggestion. At this time, we believe that establishing an emissions limit based on a 0.5 percent sulfur cap for MGO is likely to result in a supply issue at some port locations. This would be especially true for ports in areas of the world that import marine distillate from refineries that use crude oil with a high sulfur content.

For example, South Korea imports all of their crude oil, and most of it comes from the Persian Gulf region. Persian Gulf crude oil is typically "sour" crude, meaning that it has a relatively high sulfur content that typically ranges from 0.8 to 2.3 percent. This high sulfur content is reflected in the DMA sample data summarized in Table VI-3, which lists Korea as having the highest average sulfur content of those countries listed at 0.81 percent. (Starcrest, 2005; Blumberg, 2003).

Availability of Low-Sulfur Marine Distillate Fuel

As noted previously, the proposed regulation limits emissions, starting in 2010, to levels based on the use of 0.1 percent sulfur marine distillate. It is important to note that this requirement is consistent with the recently adopted European Union Directive 2005/33/EC, which establishes a 0.1 percent sulfur standard for marine fuels used by

seagoing vessels at berth in European Union ports starting January 1, 2010. (EU, 2005).

In an earlier version of the staff's proposal, we explored the feasibility of an emissions limit based on 0.2 percent sulfur marine distillate beginning in 2006. We evaluated the availability of low-sulfur marine distillates and determined that low-sulfur marine distillate with a sulfur content of 0.2 percent or less cannot be reliably supplied in most port locations and there are many unanswered questions regarding the ability of the worldwide fuel market to make adjustments that would enable them to reliably supply the fuel in the near-term. These findings are presented in Appendix I.

Based on the findings discussed in Appendix I, staff concluded it was not feasible to implement a requirement to use 0.1 or 0.2 percent marine distillate fuel in the near term (i.e., before 2010) without having additional information about world-wide fuel supplies and refining capacities. As such, staff revised the proposal to its current version, which retains the majority of the emissions benefits and ensures that fuel will be available to comply with the proposed regulation in the near-term.

While the proposal retains an emissions limit based on the use of 0.1 percent low-sulfur fuel in 2010, many of the same concerns associated with the availability of less than 0.2 percent sulfur by weight marine distillate also apply to 0.1 percent sulfur marine distillate. To address these concerns, the proposed regulation contains a feasibility review provision to ensure the fuel supply issues are thoroughly evaluated prior to implementation.

Under the review provision, the Executive Officer would evaluate by 2008 the feasibility of the 0.1 percent sulfur limit. This evaluation would take into consideration the availability of the low-sulfur fuel at bunkering ports worldwide; the ability of petroleum refiners and marine fuel suppliers to deliver the fuel by the January 1, 2010 implementation date; the fuel lubricity and compatibility with heavy fuel oil during fuel transitions; and the costs of the fuel compared to marine gas oil with a sulfur content of greater than 0.1 percent. If the Executive Officer determines that modifications are necessary, the Executive Officer would propose changes to the Board prior to January 1, 2009.

By harmonizing with the 2010 EU requirements for low sulfur marine distillates, the staff's proposal promotes international consistency and increases the availability of cleaner marine distillates at ports that refuel Pacific Rim vessels.

B. Feasibility of Using Distillate Marine Fuels in Ocean-going Vessel Auxiliary Engines

Currently, most ocean-going vessels use either heavy fuel oils or marine distillate fuels in their auxiliary engines. According to ARB's 2005 Ship Survey ("Survey"), approximately 75 percent of the engines subject to the proposed rule currently use heavy fuel oil, while the other 25 percent use distillate fuels such as marine gas oil or marine diesel oil. For the 75 percent of the engines that currently use residual fuel, the

proposed regulation would likely result in ship operators switching to distillate fuel prior to entering within 24 nm of the California coastline, assuming the operator selected this compliance option.

Because heavy fuel oil is virtually a solid at room temperature, it is heated to reduce its viscosity to the point where it can be pumped and injected into marine engines. Once liquefied, heavy fuel oil behaves much like ordinary diesel in the engine. By contrast, marine distillate fuels are liquids at room temperature, with properties already similar to typical on-road diesel fuel.

When an engine switches from one fuel to another, a transition period is generally needed to minimize rapid temperature changes; reduce fuel gassing; and ensure smooth, steady-state operation of the engine, as discussed in more detail below. To accomplish this transition period, vessel operators typically use a mixing tank. The operator steadily increases the ratio of distillate fuel to heavy fuel oil in the mixing tank, which eventually results in only distillate fuel being fed into the engine.

Considering the available information as discussed below, we believe that vessel operators can safely make this fuel switch and continue to operate their auxiliary engines with distillate fuels while operating off California's coastline. We also note these engines are certified by the manufacturer to International Maritime Organization nitrogen oxide emission standards through engine testing while the engine is operating on a distillate fuel, since heavy fuel oil properties are too variable. (IMO Annex VI) In addition, the European Union adopted a rule that will require the use of 0.1 percent sulfur fuel at dockside in 2010, which will also require these engines to switch to distillate fuel since heavy fuel oil is not available at this low sulfur level. (EU). Finally, we note that the ACP provisions in the proposed regulation allow a vessel operator to achieve equivalent emission reductions by other means if the operator chooses not to use distillate fuel.

Existing Practice

Marine vessels currently perform the same type of fuel switches that are likely to occur under this regulation. Vessel operators perform many of these fuel switches prior to dry-dock maintenance operations to prevent heavy fuel oil from solidifying in fuel lines and engine components after engine shut down.

More importantly, there are also some vessels that routinely switch from heavy fuel oil to distillate fuels during California port visits. Specifically, NYK Line, a major container ship operator, reported that they are using low (0.2 percent) sulfur marine diesel oil in their auxiliary engines on 9 to 12 vessels while hotelling at the Port of Los Angeles. (NYK Line, 2004; NYK Line, 2005) These vessels use auxiliary engines made by three different engine manufacturers, and NYK Line reported no operational problems with their use of low-sulfur MDO.

Another example involves four steel coil carrier vessels operated by USS-POSCO Industries. In these vessels, the operators switch from heavy fuel oil to ultra-low (less than 0.05 percent) sulfur diesel two to three hours prior to entering the Bay Area Air Quality Management District boundary on their regular routes between South Korea and Pittsburg, California. (McMahon) These fuel switches have been performed since the early 1990's to facilitate the use of on-board selective catalytic reduction emission control systems used to reduce emissions of nitrogen oxides.

Further, some passenger liners regularly switch fuels for air quality reasons. For example, Carnival Cruise Lines, a major passenger cruise line, reported that it is company policy to switch to distillate MDO fuel when their vessels are within 3 miles of the California shore. (Carnival, 2005a; Carnival 2005b) Another cruise line, Crystal Cruises, also reported that it switches to MDO near California ports to reduce smoke, and that cruise line has not had any operational problems with this practice. (Crystal Cruises, 2005) Further, Marine Transport Lines, which operates under contract with the United States Maritime Administration, also reported that it switches to distillate fuel in its vessels prior to entering the Bay Area. (MTL, 2005)

Finally, we should note that switching to distillate fuels upon entry to port was a standard practice for most diesel powered vessels in the past, when it was difficult for main engines to operate reliably on heavy fuel oil during maneuvering and low load operation. The use of less expensive heavy fuel oil in auxiliary engines, and main engines during maneuvering, is a relatively recent development made possible by improvements in fuel heating technology. (BMT, 2000)

Vessel Fuel Infrastructure Needs

Most vessels are equipped to run their auxiliary engines on either distillate fuel or heavy fuel oil. Less than 10 percent of the vessels that participated in the ARB Ship Survey reported the need for vessel modifications to use marine gas oil in their auxiliary engines. Specifically, 32 out of 358 vessels were reported to need modifications. These changes may or may not require that the vessel be dry-docked. Dry-dock maintenance typically occurs every five years, and many other maintenance operations are performed while the vessel is at dockside.

For vessel operators that reported the need to modify their vessels, the following types of changes were reportedly required:

- segregate an existing fuel tank for MGO;
- convert an existing heavy fuel oil tank to use MGO;
- add a fuel cooler;
- modify fuel pumps and injectors; and/or
- add a mixing tank and separate fuel treatment system.

Although most vessels have multiple fuel tanks, they may not have adequate capacity in their distillate fuel tanks to operate in the waters covered by the proposed regulation.

This is particularly true for diesel-electric vessels, and “mono-fueled” vessels (i.e., vessels that normally operate both their main and auxiliary engines on heavy fuel oil). In these cases, vessel owners may need to add a new tank, convert an existing heavy fuel oil tank to use MGO, or segregate an existing tank by installing a barrier inside the tank.

If a new or segregated tank is required, ancillary equipment such as pumps, piping, vents, filling pipes, gauges, and manhole access would be required, as well as tank testing. (Entec, 2002) In addition, fuel processing systems include settling tanks, filters, and centrifuges. While some vessel operators may be able to use their existing processing systems, other operators have reported that they will need to add to these systems, along with increased fuel capacity or other modifications.

As noted previously, mixing tanks are used to assist in a gradual transition from one fuel to another. (Wartsila, 2005a) As discussed below, sudden changes in fuel temperature or viscosity may cause damage to fuel pumps and injectors. One Survey participant reported that a mixing tank would be necessary. Fuel coolers may also assist in controlling fuel temperatures and viscosity during fuel transitions. One Survey participant reported the need for a fuel cooler.

Some Survey participants also reported the need to modify engine components such as fuel pumps, injectors, and nozzles. However, engine manufacturers have stated that, with certain caveats, the engines they designed for heavy fuel can also operate on MGO. (Wärtsilä, 2004; Caterpillar, 2005; MAN B&W, 2005; Pielstick, 2004; Yanmar, 2005)

Fuel Switching Procedures and Safety

As discussed above, marine engines can operate continuously during transitions between heavy fuel oil and distillate fuels. Procedures for conducting these transitions are well known since vessel operators perform these transitions prior to dry-dock maintenance. Engine manufacturers and marine equipment suppliers publish guidance for vessel operators that explain the recommended procedures. (MAN B&W, 2001; Aalborg) These procedures are designed to ensure a transition period from one fuel to another that controls temperature changes and ensures minimum fuel viscosity levels are maintained.

Engine manufacturers have commented that problems can occur if the transition is conducted too quickly, including fuel pump or injector scuffing, seizure, or cavitation, and fuel gassing. However, based on the fact that many vessels routinely transition from heavy fuel oil to distillate fuel, and virtually all vessels do this prior to dry-dock maintenance, we believe that vessel operators are well equipped to safely handle these transitions. We also note that equipment is available to vessel owners to automatically handle these fuel transitions.

As noted previously, we believe the safety of fuel transitions is amply demonstrated by the many vessels that routinely perform them. There are no problems reported for the vast majority of these fuel switches. However, there is a slight risk that temporary engine failure may occur if the vessel operator does not correctly follow procedures, possibly resulting in some loss of electrical power to the vessel. In these cases, a vessels' emergency backup generators, which run solely on marine distillate fuel, would become operational.

For diesel-electric vessels, which generally have several large diesel generator sets that provide power for both propulsion and onboard electrical power, a temporary failure in one or more engines could compromise vessel maneuverability to some degree. However, we do not believe fuel switching on diesel-electric vessels raises a significant problem for a number of reasons. First, the proposed regulation permits, but does not require, vessel operators to switch to the lower-sulfur distillate fuels. As we discussed previously, vessel operators can choose to comply with the regulation's emission limits with one of several options, only one of which is switching to the low sulfur fuels. Those vessel operators who believe fuel switching may cause problems that raise safety concerns have other options with which to comply. Second, as mentioned above under "existing practice," many diesel-electric cruise vessels currently switch to cleaner distillate fuels near California ports on a routine basis. Third, because there are generally several engines on diesel-electric vessels, it is likely that some engines would remain operational, providing the necessary power to the ship's systems. Fourth, the U.S. Coast Guard and shipping associations have recommended in some cases that fuel transitions in propulsion engines be performed away from confined areas. (PSSOA, 1999) The proposed regulation is entirely consistent with these recommendations because the 24 nautical mile boundary in the regulation would generally result in fuel transitions being performed in open water, for those operators that choose to switch fuels. Arguably, switching fuels at or prior to entering the 24 nm, should provide a greater margin for safety than conducting the switch much closer to the ports, which is the practice for some vessels.

Technical and Safety Considerations

ARB staff contacted the major manufacturers of auxiliary engines used on ocean-going vessels to determine whether these engines could operate on marine distillate fuel (marine gas oil or marine diesel oil). Based on our requests for information, engine manufacturers uniformly reported that their auxiliary engines designed for use with heavy fuel oil can also use distillate fuels. (Wartsila, 2004; Caterpillar, 2005; MAN B&W, 2005; Yanmar, 2005; Pielstick, 2004) However, they noted that certain technical and safety considerations need to be observed with the use of distillate fuels and during the transition from one fuel to another.

Given this, we believe that vessel operators already can and do safely use distillate fuels when they follow the engine manufacturers' recommendations. In some cases, modifications may need to be made to the fuel supply and processing equipment on the vessel. Each of these technical considerations is discussed below.

Fuel Compatibility: Engine manufacturers have commented that there is always a risk of fuel incompatibility when blending two fuels, particularly between heavy fuel oil and distillate fuels (especially very low sulfur distillate fuels which tend to be low in aromatic hydrocarbons). The main concern is that aromatic hydrocarbons in heavy fuel oil keep asphaltene compounds in solution, and the introduction of lower sulfur (often low aromatic) fuels may cause some asphaltene compounds to precipitate out of solution and clog fuel filters.

Much of the available information on this subject is focused on continuous blending of low sulfur distillate fuels with high sulfur heavy fuel oils to produce 1.5 percent sulfur fuel for Sulfur Emission Control Areas in Europe. In these situations, there may be a greater potential for filter plugging to occur than during the temporary mixing of fuels that occurs during the switchover from one fuel to another. Nevertheless, manufacturers have stated that incompatibility problems are a concern during fuel transitions as well. However, as noted above, many vessels routinely transition from heavy fuel oil to existing marine distillate fuel without incident, and virtually all vessels do this prior to dry-dock maintenance.

We also note that some manufacturers have stated that the potential for incompatibility problems is more of a concern with the very low sulfur on-road fuels which tend to have the lowest aromatic levels. (CIMAC, 2004; MAN B&W, 2005) The proposed regulation limits emissions based on the use of regular MGO, or MDO at or below 0.5 percent sulfur, starting January 1, 2007. As such, the distillate fuels used under the proposed regulation would be essentially the same fuels vessel operators now use when performing fuel transitions.

The proposed regulation also specifies a 0.1 percent sulfur level for 2010, consistent with a European Union Directive for vessels at dockside. (EU) However, as specified in the proposed regulation, ARB staff will conduct a feasibility study prior to 2010 to investigate fuel compatibility as well as other issues, prior to implementing this fuel.

Compatibility of Lubricants with Low Sulfur Fuels: Marine engine lubricants are matched to the expected sulfur content of fuel. Specifically, sulfur in fuel results in acidic compounds in the engine that are neutralized by alkaline calcium compounds in the engine lubricant. Higher "base number (BN)" lubricants are able to neutralize higher sulfur fuels. When a relatively high BN lubricant is used with a low sulfur fuel, calcium deposits can form in the combustion chamber.

These problems are primarily associated with slow speed two-stroke engines, rather than the four-stroke engines covered by this proposed regulation. (DNV, 2005) One manufacturer stated that the effect of using low sulfur fuel with a relatively high BN lubricant is a long-term issue for four-stroke engines, whereas the impact is more immediate for two-stroke engines. (Wartsila, 2005b)

For four-stroke engines that temporarily use lower sulfur fuels with a relatively high BN lubricant, problems are generally not expected unless low sulfur fuel is used for extended periods of time. One engine manufacturer recommends that their four-stroke engines can continue to use the same high BN lubricant when a heavy fuel oil engine alternates between heavy fuel oil and distillate fuel. (*Ibid*) Another manufacturer reported that their heavy fuel oil engines are expected to be able to operate for up to 300 hours on marine gas oil with high BN lubricants. (Yanmar, 5/1/05) We do not expect vessels to spend close to 300 hours of operation while traveling within 24 nautical miles (nm) of the California coastline. This is because a vessel would only need 40 hours to travel at 20 knots along the entire 800 nm California coastline.

Lubricity: Several sources reported that lower sulfur fuels have lower lubricity, which could potentially cause fuel pump damage. (DNV, 2005, App I; CIMAC, 10/04; MAN B&W, 5/05) Some of these sources noted that low sulfur automotive diesel fuels have a minimum lubricity requirement, unlike marine fuels. However, the concern appears to be related to the use of very low sulfur levels associated with landside diesel fuels, which have a lower sulfur content than what the proposed regulation specifies. For example, one source states that sulfur levels below 0.05 percent, in conjunction with a viscosity below 2 centistokes, could lead to fuel pump problems. (DNV, 2005, App. I) Another source reported that lubricity is not considered a problem for their four-stroke engine fuel injectors as long as the sulfur content is above 0.01 percent. This source mentioned that insufficient information was available to determine if fuel below this level would be problematic, but noted that lubricity additives could be added by the fuel manufacturer or marketer. (Wartsila, 2005b) As noted previously, ship operators can comply with the proposed regulation through the use of marine gas oil with no sulfur limit, or through the use of marine diesel oil with a relatively high sulfur limit of 0.5 percent in 2007. For 2010, there is a lower 0.1 percent sulfur limit. However, this limit will be subject to a feasibility review that will consider this and other technical concerns prior to implementation.

Low Viscosity: One manufacturer noted that the low viscosity of distillate marine fuels could potentially be a concern with some of their engines. One of the potential impacts of low fuel viscosity is greater internal leakage in fuel pumps and injectors, resulting in lower fuel pressures, and less fuel delivered. (DNV, 2005) According to one manufacturer, the minimum viscosity of fuel supplied to their engines is in the range of 1.8 to 3 centistokes, and noted that minimum viscosity for marine gas oil (DMA) is 1.5 centistokes. However, this manufacturer also noted that for their four-stroke engines low fuel viscosity is generally not a severe problem. The manufacturer suggested that a minimum viscosity could be specified when ordering distillate fuels, or modifications could be made to address this issue. (Wartsila, 2005b) One possible modification would be a fuel cooler since lowering the fuel temperature will increase its viscosity.

Fuel Energy Content Differences: Marine distillate fuels have less energy than heavy fuel oils on a volume basis. Some manufacturers have commented that this will reduce the output of a four-stroke engine by approximately 6-15 percent depending on the

engine model. (Wartsila, 2005b; Yanmar, 2005; Pielstick, 2004) Depending on the engine, governor adjustments or a change in the fuel "rack" position may address this issue.

Pipe Leakage: Use of less viscous marine distillate fuels, and temperature changes that occur during transitions between heated heavy fuel oil and non-heated distillate fuel have been reported to increase the likelihood of fuel leaks. However, such leaks would also be expected to occur during fuel transitions performed prior to dry-dock operations. Such leaks can be prevented through maintenance, such as replacement of deteriorated gasket materials or o-rings, and tightening connections.

C. Potential Options for Alternative Control Plans

Below, we provide descriptions of diesel PM and NOx emission reduction control strategies that potentially could be used as compliance options under an alternative control plan. These technologies are currently available or projected to be available in the near future. In many cases, similar technologies have been used on stationary diesel engines, which are operated similarly to vessel auxiliary engines. Each technology may not be by itself an alternative emission control strategy, but used in combination with other technologies may equal or exceed the required emission levels of the proposed regulation. Additional information on the wide variety of emission reduction options for diesel fueled engines is provided in the Diesel Risk Reduction Plan. (ARB, 2000)

Cold Ironing or Alternative Marine Power

This option would allow vessels to use dockside electrical power (cold ironing) during hotelling, instead of operating ship-board auxiliary diesel engines to provide electric power. Although there are technical challenges associated with providing cold ironing for vessels, this process is currently being used by several West Coast ports. For example, the Princess Cruise vessels that dock in Juneau, Alaska and Seattle, Washington use shore-side power for hotelling.

USS-POSCO industries has four vessels that have been cold ironing at a Pittsburg, California terminal since the early 1990s. The Port of Los Angeles retrofitted the China Shipping terminal to include shoreline power infrastructure. Two China Shipping vessels began connecting to shore power in June 2004, with the goal of 70 percent of the vessels visiting the terminal using shore power. Also at the Port of Los Angeles, shore-side infrastructure is currently being constructed to allow an NYK Atlas container vessel already built with cold ironing capabilities to use shore-side power. The Port of Long Beach will also provide cold ironing capabilities for two British Petroleum tankers that regularly visit the port. Finally, the U.S. Navy has been cold ironing in port at bases all over the world for several decades.

Selective Catalytic Reduction (SCR)

Selective catalytic reduction (SCR) is an exhaust after-treatment method for controlling NO_x emissions up to 90 percent or more. The SCR process basically works by using ammonia (NH₃) as a reagent, injecting it into the exhaust gas of the engine, in the presence of a catalyst. The ammonia and NO_x emissions react in the presence of the catalyst to form nitrogen (N₂) and water. Atmospheric nitrogen is usually in its diatomic form of N₂ and the water is non-polluting. The ammonia is injected into the process with air or steam.

SCR systems have been installed on new marine engines for many years. For example the four USS-POSCO vessels mentioned above are equipped with SCR on their main engines. However, retrofitting SCR systems on existing vessels is challenging. Some SCR retrofit challenges are urea and ammonia storage and safety requirements. Also, SCR systems require a large amount of space near the engine.

Diesel Oxidation Catalysts

Diesel oxidation catalysts (DOCs) have been used on many land-based engines. DOCs are generally referred to as "catalytic converters." DOCs are devices attached to the engine exhaust system similar to a muffler. They have chemical catalysts dispersed on a substrate within their interior which assist in the oxidation of carbonaceous pollutants – some of the soot emissions and a significant portion of the soluble organic fraction of diesel PM. These carbon-containing pollutants are oxidized to CO₂ and water. The catalysts that are used are known as the platinum group metals. These consist of platinum, iridium, osmium, palladium, rhodium, and ruthenium. Platinum is best suited as the catalyst for diesel engine control devices; therefore, it appears that it will be the main catalyst used in diesel catalytic converters. (Kendall, 2002/2003)

Flow Through Filters

Flow through filter (FTF) technology is a relatively new technology for reducing diesel PM emissions. Unlike diesel particulate filters (DPF), in which only gases can pass through the substrate, the FTF does not physically "trap" and accumulate PM. Instead, exhaust flows through a medium (such as wire mesh) that has a high density of torturous flow channels, thus giving rise to turbulent flow conditions. The medium is typically treated with an oxidizing catalyst that is able to reduce emissions of PM, HC, and CO, or used in conjunction with a fuel-borne catalyst. Any particles that are not oxidized with the FTF flow out with the rest of the exhaust and do not accumulate. Also, limiting the sulfur fuel content to <350 ppm or less will limit clogging and reduce backpressure problems.

The filtration efficiency of an FTF is lower than that of a DPF, but the FTF is much less likely to plug under unfavorable conditions, such as high PM emissions, low exhaust temperatures, and emergency circumstances. The FTF, therefore, is a candidate for use in applications that are unsuitable for DPFs.

Advanced Control Technology Inc. Technology

Advanced Control Technology Inc. (ACTI) has developed an emission reduction technology that they claim has the potential to remove 95 percent of NOx emissions and 90 percent of PM emissions. The system would reduce emissions from marine engine auxiliary engines while at port by placing a flexible hood over the exhaust stack. The flexible hood would be placed over the exhaust stack by a robotic arm, diverting the exhaust into a two stage "wet scrubbing" process where the pollutants would be removed. The system would be placed on a mobile barge. (ENN, 2005) Currently, ACTI is installing this technology at the J.R. Davis Roseville, California rail yard. Testing will follow with the goal of U.S. EPA certification. (ARB, 2005)

Slide Valve Technology

Replacing stock fuel injectors with slide valve fuel injector technology can result in a PM reduction of up to 50 percent, depending on the engine load. Standard fuel injectors leave a residual volume of fuel that remains in the injector after the fuel is injected into the cylinder. The remaining fuel drips into the cylinder during the non-combustion portion of the stroke, causing soot and PM. The new slide valve technology reduces the residual fuel volume to a minimum, thereby reducing soot and PM emissions. Most engine companies are installing slide valve technology on their new engines as standard equipment and also offering slide valves during normal injector maintenance replacement. (Man B&W)

Common Rail

Fuel pressure is distributed evenly to the injectors by an accumulator or rail. The high pressure is supplied by a pump. The rail pressure, at the start and the end of the injection is controlled electronically. The common rail system offers the following advantages: high fuel pressure at all engine speeds, ability to offer pilot injection and post injection at all engine speeds, and most conventional injection systems can be replaced with a common rail system without major engine modifications. (DieselNet, 2002a)

Water Injection

Adding water to the combustion chamber absorbs heat when the water vaporizes, lowering the peak combustion temperatures and reducing NOx emissions. Water can be introduced in a variety of ways: direct water injection, fumigation into the intake air, or with the fuel in an emulsion. Unmodified engines can use emulsified fuel, if the injection systems can handle the extra volume. Other systems require major redesign to include separate water supply tanks, injection lines, fuel pumps, injectors, etc. Generally, a 1 percent increase of water equates to a 1 percent decrease in NOx emissions. However, hydrocarbon and carbon monoxide emissions may increase using water injection strategies. (DieselNet, 2003)

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